How the Space Data Center Is Improving Safety of Space Operations

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ABSTRACT

In an effort to mitigate the risks associated with satellite close approaches in the geostationary belt, satellite operators began to come together in early 2008 to establish a prototype GEO data center. That prototype provided a framework for operators to share orbital data for their fleets to be used to perform conjunction analysis and provide automated notifications of close approaches via the SOCRATES-GEO service. That service was extended to LEO operations in mid-2009 and, as of early 2010, the prototype was supporting 20 operators from over a dozen countries by automatically screening 300 satellites for close approaches twice each day.

In April 2010, the prototype data center operated by the Center for Space Standards & Innovation (CSSI) was a key reason AGI was selected by the Space Data Association (SDA) to develop the SDA's new Space Data Center (SDC). This paper will address how the SDC will use a service-oriented architecture (SOA) to support orbital operations by increasing the efficiency of analysis to mitigate the risk of conjunctions and radio frequency interference, thereby enhancing overall safety of flight.

1. INTRODUCTION

By now, we all have seen the statistics: Since the beginning of 2007, the number of objects in the public satellite catalog has grown from 10,136 objects in Earth orbit to 16,068 today—an increase of almost 60 percent in just over three years. Eighty percent of these new objects are the result of just two events: the January 2007 Chinese test of an anti-satellite weapon against FengYun 1C (2,944 objects on orbit) and the February 2009 collision of Iridium 33 and Cosmos 2251 (1,786 objects on orbit). As of today, less than 4 percent of the total 4,912 pieces of cataloged debris objects have decayed from orbit and many will remain in orbit for decades or centuries to come, creating a continuing hazard for space operations.

In fact, the debris from these two events have already considerably complicated operations for satellite operators in low-Earth orbit—operating constellations such as the Iridium, Orbcomm, and Globalstar communications networks and many Earth resources satellites. For Iridium and Orbcomm alone, these debris now account for half to two-thirds of all predicted close approaches, or conjunctions, within 5 km of their satellites—or more than double the number from before 2007—as seen in Table 1. Obviously, the space operations community needs to work together now to reduce the likelihood of similar events happening again.

Table 1. Operational Iridium and Orbcomm Conjunctions

	Fengyun 1C Debris	Iridium 33 Debris	Cosmos 2251 Debris	All	Percentage of All
Operational Iridium	321	193	754	1,907	66%
Operational Orbcomm	85	80	79	437	56%

Results from SOCRATES-LEO run of 2010 September 5 at 1200 UTC.

The good news is that the international community has already been working together since early 2008 to share orbital data with the goal of mitigating the risk of additional on-orbit collisions. In order to understand the benefits of this collaboration and see how to improve its effectiveness, we will need to first understand the limitations of today's space surveillance systems for helping to avoid conjunctions and how data sharing can overcome some of those limitations.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **SEP 2010**	2. REPORT TYPE	3. DATES COVERED **00-00-2010 to 00-00-2010**

4. TITLE AND SUBTITLE **How the Space Data Center Is Improving Safety of Space Operations**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Center for Space Standards & Innovation,7150 Campus Drive, Suite 260,Colorado Springs,CO,80920**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

2010 Advanced Maui Optical and Space Surveillance Technologies Conference, 14-17 Sep, Maui, HI. Sponsored in part by AFRL. U.S. Government or Federal Rights License

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15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**5**	

2. BACKGROUND

The debris statistics provided above were derived from the public data released from the US Space Surveillance Network (SSN) catalog. That network is a collection of dedicated, collateral, and contributing radar and optical sensors designed and built in the 1960s, 1970s, and 1980s for an entirely different purpose than collision avoidance—to track Soviet satellites and detect incoming ballistic missiles. To perform these missions, the radars of the SSN were designed to be capable of tracking objects 10 cm or larger in low-Earth orbit (LEO; out to 5,000 km) while the optical sensors (telescopes) are capable of tracking objects 1 meter or larger in geostationary orbit (GEO; around 36,000 km).

With these capabilities, the SSN currently tracks over 22,000 objects [1]. Only 16,000 of these objects are in the public catalog, however, and available to satellite operators for screening close approaches with their satellites. The remaining 6,000 objects are kept in a separate catalog because they need additional work to refine their orbits and define their origin [2]. And NASA currently estimates more than 500,000 objects in Earth orbit 1–10 cm in diameter—each more than capable of disabling a satellite in a hypervelocity impact—few of which can be tracked by the SSN [3].

To further complicate the problem, the SSN was specifically designed to use noncooperative tracking—that is, tracking each space object without any type of active cooperation from the object itself. In order to provide tracking on as many objects as possible, the SSN obviously cannot rely on cooperative tracking from debris or satellites whose operators may not wish to cooperate. Noncooperative tracking works reasonably well for debris objects, but presents significant limitations when tracking operational spacecraft, since this method must detect and process maneuvers after the fact—resulting in delays in providing updated orbits. And detecting maneuvers on GEO satellites can be even more challenging since current ground-based optical systems are not capable of day-night, all-weather operations—potentially delaying the acquisition of observations immediately following a maneuver. Under such conditions, satellite orbit estimates can degrade, resulting in the SSN being unable to associate new observations with the correct satellite (cross-tagging) or even 'losing' the satellite. As a result, even the objects that can be tracked by the SSN may not be tracked accurately enough to provide satellite operators confidence in their conjunction predictions.

Given the current state of affairs, it would seem that there is little that satellite operators can do to protect their satellites. Yet, we will see that a more thorough review of existing complementary capabilities suggests that parts of the problem can be addressed through collaboration, freeing up more capable resources to focus on the particularly challenging aspects of providing improved space situational awareness (SSA).

3. METHODOLOGY

As with any complex problem, the solution to this problem will not be simple. There are many facets to improving SSA which provide opportunities to quickly leverage existing capabilities to move toward immediately mitigating the risk of on-orbit collisions. A judicious approach of starting with the most immediate opportunities, while identifying potential ways to address other shortcomings, should achieve the most expedient results.

We can begin by turning one of the primary limitations of the current SSN into an advantage by realizing that while each maneuvering satellite can be difficult to track using noncooperative tracking, that each of these satellites is operational—which means that there is an operator responsible for maintaining its orbit. Satellite operators must maintain accurate orbits for their satellites in order to be able to plan state-of-health contacts and support anomaly resolution, thermal and power management, attitude maintenance, periodic orbit adjustments, and ensure regulatory compliance. In most cases, today's satellite operators use active ranging or onboard GPS to provide orbits which have been shown to be an order of magnitude better than noncooperative tracking can produce and which ensure the proper identification (correlation) of the observations [4]. And, of course, the satellite operator knows when maneuvers are planned to be conducted and what the post-maneuver nominal orbit should be.

In fact, this realization was the basis for establishing the current prototype data center, operated by the Center for Space Standards & Innovation (CSSI) on behalf of its members. The data center supports 20 satellite operators from a dozen countries, as seen in Table 2. CSSI screens 286 of their satellites—in both LEO and GEO—which represents over one-quarter of all operational satellites in Earth orbit. These conjunction screenings are

automatically performed twice each day, using the best orbital data available, and take a combined time of just over 17 minutes on a standard desktop computer to produce. Each operator provides their own orbital data—including planned maneuvers—to CSSI for these conjunction assessments.

CSSI ensures that all operator data is correctly transformed to standard orbital data formats for subsequent use. Correctly understanding the wide variety of data formats, coordinate systems, and time systems is critical to accurate conjunction analysis. Converting that data to standard data products that operators can directly ingest into their systems exercises the process of ensuring that the exchange of vital orbital data can be handled in time-sensitive situations. And regular validation of the operator ephemeris products helps assure consistent data quality and promotes best practices in orbit determination techniques. When this data is combined with SSN data for non-member satellites and debris, it provides the best overall SSA for screening close approaches available today.

Table 2. Current Prototype Data Center Participants

Operator	HQ	Satellites	Operator	HQ	Satellites
Intelsat	Luxembourg	65 GEO	Optus	Australia	4 GEO
Inmarsat	UK	11 GEO	Indovision	Indonesia	2 GEO
EchoStar	US	8 GEO	Sky Perfect JSAT	Japan	5 GEO†
SES	Luxembourg	44 GEO	Telkom	Indonesia	0 GEO†
NOAA	US	5 GEO	Iridium	US	74 LEO
Star One	Brazil	6 GEO	Orbcomm	US	17 LEO
Telesat	Canada	23 GEO, 1 LEO	GeoEye	US	2 LEO
EUMETSAT	Germany	4 GEO	DigitalGlobe	US	3 LEO
IAI	Israel	2 GEO	Canadian Space Agency	Canada	2 LEO
Paradigm	UK	7 GEO	GISTDA	Thailand	1 LEO
Total: 186 GEO, 100 LEO					

†*Additional satellites being worked*

Operators are able to specify threshold conditions and values to be used in providing automated warnings (e.g., any object coming within 25 km of any of their satellites). Operators have full access to the conjunction analysis in an access-controlled online system, which includes the orbital data used for the conjunction assessments, so that they can quickly and reliably perform additional analysis to determine whether they wish to perform a collision avoidance maneuver and what the most efficient maneuver would be, based upon their mission requirements.

Inmarsat, Intelsat and SES have now moved forward to formalize the successes of the prototype data center concept—establishing the Space Data Association Ltd. (SDA) in late 2009 [5]. SDA is dedicated to safe and responsible satellite operations, including the prevention of collisions in space and improving satellite communications. SDA provides the legal basis and organizational resources to make the prototype data center fully operational.

To that end, SDA selected Analytical Graphics, Inc. (AGI) after a competitive RFP process to develop and operate the new Space Data Center (SDC) [6]. The SDC is the satellite industry's first global operator-led network for sharing high-accuracy operational data to improve overall space situational awareness and satellite operations. SDC reached initial operational capability on 2010 July 27 and will achieve fully operational capability in Q1 of 2011.

4. CONCLUSIONS

Not only does the Space Data Center provide improved SSA for satellite operators and support more efficient decision making, it could be used by the Joint Space Operations Center (JSpOC) at Vandenberg AFB to improve their SSA, too. Instead of having to dedicate additional resources to closely tracking and recovering maneuvering satellites, the JSpOC could simply use the SSN to verify the operator-reported orbits from the SDC periodically,

freeing up SSN resources for tracking noncooperative objects. If problems were detected during verification of certain satellite orbits, the JSpOC would simply fall back to the standard noncooperative tracking approach.

Of course, to encourage maximum participation by satellite operators in such a data sharing arrangement, the US must be willing to reciprocate by sharing the best available orbital data they have on as many objects as possible. That means US data policy should be changed to support the release of high-accuracy orbital data—in line with the new US national space policy [7]. Given that over 95 percent of the 22,000 objects currently tracked by the SSN are dead satellites or debris and less than 1 percent are operational US Department of Defense or intelligence satellites, why wouldn't the US want to share this data if it meant helping to avoid a repeat of the Iridium 33 collision with Cosmos 2251—a dead Russian communications satellite? Sharing this data with the satellite operators would also allow the operators to perform their own conjunction screenings, reducing the need for the JSpOC to take on that task for them and helping to raise the bar for operator best practices.

Having more accurate orbital data would significantly reduce the number of false alarms, which currently undermine operator confidence in conjunction assessments. An order of magnitude improvement in accuracy reduces the threat volume by a factor of 1,000 and makes the collision avoidance problem far more manageable.

Even if there were a problem with releasing the entire high-accuracy catalog to the public, allowing it to be used by the SDC for screening close approaches—and only releasing orbital data to satellite operators for individual conjunction events involving their satellites—would go a long way toward reducing the risk of another collision in orbit.

4.1. Need for Additional Collaboration

The establishment of the SDC in such a short period of time is a great step forward in developing a global network of satellite operators working together to reduce the risk of on-orbit collisions. But much work remains to be done to bring in other satellite operators into the system. After all, the more operators that participate in such a system, the more benefit will be seen by all.

Bringing in high-accuracy data from the SSN would also be a big step forward—particularly for LEO operations—in providing better SSA for the large amounts of orbital debris there. But the space surveillance networks of other major space players—most notably Europe, Russia, and China—would further enhance SSA. And there is potential to bring in research networks—such as the International Scientific Observing Network—which are using very capable systems to study the orbital debris population. In order to perform their research to detect hard-to-track objects, they must also maintain catalogs of other objects—all data which could be used by satellite operators to avoid conjunctions.

Of course, NASA and European Space Agency (ESA) studies showing very large numbers of objects smaller than can be currently tracked by current space surveillance systems point out the need the need for even more capable sensors and more effective correlation techniques to match observations with objects. Here again, international collaboration could help ensure funding and a robust global view of the near-Earth space environment.

Finally, there is a continuing need to establish standards for safer space operations. Current international standards which allow dead spacecraft to remain in Earth orbit for up to 25 years are simply too lax. Iridium 33 was destroyed by Cosmos 2251, which is believed to have ceased operations two years after being launched in 1993, and then drifted for another 14 years before the collision. Obviously, we need to be much better stewards of the space environment.

4.2. Moving Forward

Clearly, there are plenty of challenges to providing improved SSA and safer space operations. The good news is that the international community is already working hard to move forward on improving things today. Participation in the SDC by satellite operators worldwide—together with national and research space surveillance networks—would continue to improve things tomorrow.

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